

For whom the disc tolls

J.-P. LASOTA^{1,2}

¹ Institut d'Astrophysique de Paris UMR 7095 CNRS

² Université Pierre & Marie Curie 98bis Boulevard Arago, 75014 Paris, France

Received 8 September; accepted 22 September 2005; published online 20 October 2005

Abstract. Report on the Nordita Workdays on Quasi-Periodic Oscillations (QPOs).

Key words: accretion, accretion discs – stars: neutron – black hole physics – QPOs

©0000 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

The publications resulting from the Nordita Workdays on QPOs are an interesting and original contribution to research on accretion flows around compact objects. They contain four observational papers, one theoretical paper dealing with numerical simulations of accretion discs and eleven contributions (some of them analyzing observations) totally devoted to the epicyclic resonance model (ERM) of high frequency QPOs (hfQPOs) of Abramowicz & Kluźniak. Probably all that is to be known about this model is included in these publications. This is their strength but also their weakness. First the model is not complete, it is rather kinematic than dynamic. It describes in great detail the interactions between two oscillations but as Kluźniak confesses: *It would be good to identify the two non-linear oscillators*. Yes indeed. Not only good but crucial. Second, concentrating on hfQPOs only is most probably not a wise decision because there exist (admittedly complex) relations between them and their lower frequency brethren and there is a clear link between their presence and the state of the system. Although the authors of the eleven papers sometimes pay lip-service to observations not directly concerning the frequency values of hfQPOs, in practice they seem to ignore the very important conclusion of Remillard: *... models for explaining hfQPO frequencies must also explain the geometry, energetics and radiation mechanisms for the SPL state*. By the way, probably even this will not do: the model will have to explain all the X-ray states. One can understand the reluctance to leave the clean world of resonating orbits for the dirty world of turbulent, magnetized, radiating discs with unpleasant boundary conditions, but QPOs occur in such world. Abramowicz believes that QPOs are the Rosetta stone for understanding black-hole

accretion. Not so. If one had to (over)use¹ the Rosetta-stone analogy, QPOs would be just one of the texts on this stone. Let's hope it is the Greek one. All in all, these publications are not so bad: imagine a volume devoted to the beat-frequency model. At least the epicyclic resonance model is still alive.

The authors of the papers deal only with neutron star and black-hole QPOs. The abundant QPOs observed in CVs are only mentioned en passant and no special attention is paid to them. Probably because, not being (sufficiently) relativist, they are considered boring. In view of the recently published article on the subject (Kluźniak et al. 2005) such an attitude is rather surprising.

Observations

The four contributions in this category have been written by some of the top observers of X-ray binaries and they form a very good (too good maybe) background for the theoretical papers. van der Klis, as usual, gives a clear and sober review of the QPO phenomenon. One wishes theorists paid more attention to what he has to say about black hole hfQPOs: *The phenomenon is weak and transient so that observations are difficult, and discrepant frequencies occur as well, so it can not be excluded that these properties of approximately constant frequency and small-integer ratios would be contradicted by work at better signal to noise*. Being a loyal participant he adds: *In the remainder I will assume these properties are robust*.

A usual in QPO research it is difficult to get used to the terminology and classification. It took some time to make sense of *atolls*, *bananas* and *z-tracks* (and sources!) and now we encounter the challenge of the X-ray states

Correspondence to: lasota@iap.fr

¹ The road to the theorist's hell is paved with Rosetta stones

of Black Hole Binaries. Not surprisingly Remillard is using the classification defined in his monumental work with McClintock (McClintock & Remillard 2006). We have therefore the *thermal*, *hard* and *SPL* states. One might be slightly worried not seeing the *thermal dominant (TD) state* (McClintock & Remillard 2006) but fortunately we are told that the thermal state is the *formerly “high/soft” state*, so $TD = thermal$. In any case the real drama begins when one wishes to see what other specialists have to say about the subject, e.g. Belloni (2005). There we find a different classification into: an *LS* (Low/hard state), an *HIMS* (High Intermediate State), a *SIMS* and an *HS* (High/Soft state). It seems that $HS=TD$ and $LS=hard$ but in the two other cases relations are not clear. This is not surprising because Belloni defines his states by the transition properties and not by the state properties. In addition Belloni (2005) classifies low frequency QPOs into A, B and C types, whereas Remillard uses quantities a and r , the rms amplitude and power (note that it was Remillard who introduced type C QPOs). Both approaches have their merits and one can understand why they were introduced but they make life really difficult for people trying to understand the physics of accretion flows. I am surprised that Abramowicz complains only about the confusion introduced by numerical simulations and not about the impenetrable jungle of X-ray states and QPO terminology. I suspect he has given up on reading on this subject.

However, Remillard convincingly shows that hfQPOs appear in the SPL state and shows very interesting relations between the presence of $2\nu_0$ and the $3\nu_0$ frequencies and the state of the system as described by the disc flux and the power-law flux. As far as I can tell this is ignored by the epicyclic theorists but this could be the second text of the Rosetta stone. It is also a major difficulty for the epicyclic resonance model. Since the SPL state is characterized by a strong Comptonised component in the X-ray flux, it is difficult to see how the flux modulation at the vertical epicyclic frequency by gravitational-lensing could survive in such an environment.

This brings me to the contribution by Barret and collaborators. Recently Barret with a different (but intersecting) set of collaborators (Barret et al. 2005) made a fundamental discovery by showing that the lower frequency kHzQPO in the neutron-star binary 4U 1608-52 is a highly coherent signal that can keep $Q \approx 200$ for ~ 0.1 s. They also found that the higher frequency kHzQPO is fainter than its lower frequency counterpart and has lower Q . Barret et al. (2005) showed very convincingly that no proposed QPO model can account for such highly coherent oscillations. They can all be rejected except for the ERM but only because the two resonant oscillators have not yet been identified. In particular, they rejected the modified beat-frequency model of Miller et al. (1998). In Barret et al. another puzzling phenomenon is presented. They found in three neutron-star binaries (including 4U 1608-52) showing high- Q lower kHzQPOs that the coherence increases with frequency to a maximum (~ 800 Hz) after which it rapidly drops and QPOs disappear. To me it looks like an effect related to the forcing mechanism. Barret et al. link their observations to the ISCO basing their claim on

the Miller et al. (1998) model. There is half a paragraph trying to explain (I think) how the model rejected in a previous paper can be rejuvenated (or rather resuscitated) and used to interpret the present observations. I read this part of the paper several times and failed to understand its meaning. I had no problem understanding the reasoning rejecting Miller et al. (1998).

In any case I also fail to understand why the Barret et al. (2005) discovery of the high coherence of QPOs was not the central point of the Nordita workdays. It is easy to miss a *Mane, Mane, Tekel, Uphar’sin* when looking for a Rosetta stone.

The main result of the excellent article on neutron-star boundary layers Gilfanov is that the kHzQPOs appear to have the same origin as aperiodic and quasiperiodic variability at lower frequency. It seems to be clear that the msec flux modulations originate on the surface of the neutron star. Nota bene, I am surprised that the remarkable and extremely relevant discovery of the universal rms-flux correlation (Uttley 2004; Uttley et al. 2005) is not mentioned in this context. Gilfanov point out that the kHz clock could still be in the disc.

Disc simulations

It is known that in stars some multimode pulsations may arise from stochastic excitation by turbulent convection (see e.g. Dziembowski 2005). It is therefore legitimate to expect that in turbulent discs similar effects could be found. Brandenburg presents very interesting results obtained in the framework of the shearing-box approximation of accretion disc structure. He obtains what he calls stochastic excitation of epicycles. In his model the radial epicyclic frequency is equal to the Keplerian frequency and the vertical epicyclic frequency is not equal (or comparable) to the p-mode frequency so it is not clear how close his results are to what is happening in full-scale discs. But they are promising. Another result concerning dissipation in discs requires more investigation. According to Brandenburg in MRI discs most of the dissipation occurs in the corona, whereas in the forced hydrodynamic case most of the dissipation occurs near the midplane. He claims that his result, obtained in the isothermal case, has been shown also for radiating discs. The disc model in question, however, was radiation-pressure dominated while gas-pressure dominated models (Miller & Stone 2000) do not seem to confirm the claim that MRI discs release most of the energy in the corona.

The epicyclic resonance model

The eleven contributions to the epicyclic resonance model contain two general articles by the founders; the other papers on different aspects of the model were written (except for the last contribution) by younger members of the ERM team. All these contributions are very well written, clear and to the point. I was really impressed by their quality. They contain all one needs to know about the ERM. As far as I know they were written by the authors whose names appear explicitly on the paper and since they are very careful in acknowledging

other people's contributions I recommend removing the "et al.'s" which give the impression that the texts were written by a sect, or that they form a sort of Norditan Creed. Fortunately this is not the impression one gets reading the articles. They are professional, open to alternatives, pointing out difficulties etc.

Of particular quality in this respect in the contribution by Paola Rebusco. She presents the problem in a very clear way and carefully chooses the (difficult) questions still to be answered. Jiří Horák contributes two interesting articles. The first discusses the 3:2 autoparametric resonance in the general framework of conservative systems and shows that the amplitude and frequency of the oscillations should be periodically modulated - a result that might relate hfQPOs to lower frequency QPOs. The second paper tries to explain the QPO modulations in neutron-star binaries by a mechanism proposed by Paczyński. It is not clear if such a mechanism could achieve the high quality factors observed by Barret et al. (2005) or how it relates to the oscillation forced by the spinning neutron-star magnetic field. Three contributions deal with various aspects of oscillating tori. Eva Šrámková presents the preliminary results of her research on eigenvalues and eigenfrequencies of slightly non-slender tori. She includes in her paper a figure showing a transient torus appearing in a 3D simulation of an accretion flow - a rather touching testimony to the ERM-team reliance on this elusive structures. William Lee uses SPH simulations to study the response of a slender torus to external periodic forcing. The results are a very interesting illustration of the essentially nonlinear character of the coupling between the radial and vertical modes (coupling through the sub-harmonic of the perturbation: $1/2\nu_0$) and the rather fascinating phenomenon of mode locking for a drifting torus. This can be relevant to the drift of QPO frequencies observed in neutron-star binaries. Since his contribution is devoted to these systems, mentioning "stellar-mass black holes" in the abstract is a bit misleading. Michal Bursa expertly attacks the problem crucial for the ERM applied to black holes: how to produce two modulations of the X-ray flux. By using a toy model consisting of an optically thin, bremsstrahlung emitting, oscillating slender torus he shows that strong-gravity relativistic effects may produce the desired result. How would things look in the case of an optically thick disc surrounded by a comptonizing cloud is (probably) a different story. The last three contributions deal with some aspects of hfQPO observations. Tomek Bulik reanalysis the somewhat controversial issue of the Sco X-1 kHzQPO clustering around the value corresponding to the frequency ratio of 2/3. His skillful analysis shows that the clustering is real. Gabriel Török has been entrusted with the somehow irksome task of linking microquasar QPOs with those observed in Sgr A* and AGNs. Since the last category forms an empty set he could just discuss why such observations would be important. Unfortunately the prospect of detecting QPOs from AGNs is rather remote (Vaughan & Uttley 2005). His valiant attempt to discuss determining black-hole spin from hfQPOs was hindered by the uncertainties in both data and models. But his is a very good short review of the problem.

Because they are a general introduction to an unfinished construction, the contributions by the founders are less interesting. Abramowicz gives a general introduction to the subject of accretion onto compact objects. In his (entirely justified) efforts to rehabilitate his and collaborators' (to whom I belong) fundamental contributions to the concept of ADAF, Abramowicz went too far: he antedated the relevant Abramowicz et al. paper by ten years and did not insert the Narayan & Yi article into the references. I think also that his claim that accretion theory today experiences a period of confusion caused by supercomputer simulations is exaggerated. The confusion is caused by (some) astrophysicists hastily trying to apply to real objects whatever comes out of the computer and not by the physicists making these very impressive simulations. People who are confused should read the excellent article by Balbus (2005) - a real guide for the perplexed. However, Eq. (2) Abramowicz can create confusion since it asserts that the radial epicyclic frequency is *larger* than the vertical one. Luckily there is his Fig. 2 to sober us up. Kluźniak with his usual charming intellectual incisiveness describes his personal road to ERM. He is convinced that after trying various roads which led nowhere, he finally chose the right one. He knows it is uphill and very steep. But never send to know for whom the disc tolls; it tolls for him. I wish him luck.

Acknowledgements. I am grateful to Marek Abramowicz for inviting me to write this report and to Günther Rüdiger for accepting this risky idea.

References

- Balbus, S.A.: 2005, ASP Conf. Ser. 330, 185 (astro-ph/0411281)
- Barret, D., Kluźniak, W., Olive, J.F., Paltani, S., Skinner, G.K.: 2005, MNRAS 357, 1288
- Belloni, T.: 2005, in: E. van den Heuvel, P. Ghosh (eds.), Proc. of COSPAR Colloquium on *Spectra and Timing of Compact X-ray Binaries*, astro-ph/0507556
- Dziembowski, W.: 2005, MmSAI, in press (astro-ph/0509451)
- Kluźniak, W., Lasota, J.-P., Abramowicz, M.A., Warner, B.: 2005, A&A 440, L25
- McClintock, J.E., Remillard, R.A.: 2006, Chapter 4 in Compact Stellar X-ray Sources, ed. W.H.G. Lewin and M. van der Klis, Cambridge University Press (astro-ph/0306213)
- Miller, K.A., Stone, J.M.: 2000, ApJ 534, 398
- Miller, M.C., Lamb, F.K., Psaltis, D.: 1998, ApJ 508, 791
- Uttley, P.: 2004, MNRAS 347, L61
- Uttley, P., McHardy, I.M., Vaughan, S.: 2005, MNRAS 359, 345
- Vaughan, S., Uttley, P.: 2005, MNRAS 362, 235